Towards a commercial lignocellulosic ethanol industry in Australia:

The Mackay Renewable Biocommodities Pilot Plant

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Abstract

In 2007, the Queensland University of Technology (QUT) received funding from the Australian Government through the NCRIS program and from the then Queensland Government Department of State Development to construct a pilot research and development facility for the production of bioethanol and other renewable biocommodities from biomass including sugar cane bagasse. This facility is being constructed adjacent to the Racecourse Sugar Mill in Mackay and is known as the Mackay Renewable Biocommodities Pilot Plant (MRBPP). The MRBPP will be capable of processing biomass through a pressurised pretreatment reactor and includes equipment for enzymatic saccharification, fermentation and distillation to produce ethanol. Lignin and fermentation co-products will also be produced at a pilot scale for product development and testing.

Introduction

As a result of the increasing scarcity of crude oil, rising oil prices and concerns about the geopolitical concentration of remaining oil reserves, many countries are now seeking alternate energy sources for transport fuels. The need for renewable and sustainable low greenhouse gas emission transport fuels is also underpinning the development of new fuel production technologies.

One of the most viable alternate fuels is ethanol and sizable ethanol transport fuel programs have been established in the USA (based primarily on corn starch) and Brazil (based on sugar cane juice and molasses sugars). These first generation ethanol fuels utilise the high value component of the crop for conversion to ethanol and concerns have been raised globally over the potential impact of the use of these feedstocks on the price of food.

By contrast, second generation biofuels utilise non-food feedstocks, such as lignocellulosic materials from forestry or agricultural residues for bioethanol production. Materials considered for second generation biofuel production are generally low value feedstocks, including crops grown on marginal agricultural land or underutilised biomass residues of existing agricultural crops.

Lignocellulosic biomass (such as sugar cane bagasse) contains three key components - cellulose, hemicellulose and lignin. Both the cellulose and hemicellulose can be pretreated, hydrolysed and fermented with varying efficiencies into ethanol (IEA, 2004; Olsson *et al.*, 2005).

While considerable research has been undertaken on the production of lignocellulosic ethanol since the early 20th century, there remain some significant challenges to the economic commercialisation of the technology. Apart from the financial challenges of developing a cost-effective process, one of the major issues for any biomass processing system is developing an efficient collection and transportation system for the high volume, low density biomass feedstock to the ethanol production facility (Childs and Bradley, 2007).

One of the most significant advantages of sugar cane as a feedstock for lignocellulosic ethanol is that large quantities of bagasse are readily available for further processing at an existing industrial facility, eliminating any additional cost for harvesting and transport, and this can potentially be supplemented with additional leaf material utilising existing harvesting and transport systems. Additionally, the potential use of existing site infrastructure and services may allow for lower capital costs for a lignocellulosic ethanol plant integrated with an existing sugar mill and conventional ethanol distillery.

The sugar cane biorefinery

A number of studies comment on the need to improve the economics of the bioethanol production process through the production of multiple co-products in an integrated biomass biorefinery (Arato *et al.*, 2005; Day *et al.*, 2008; Edye *et al.*, 2005; Erickson, 2007; Godshall, 2005; Peterson, 2006; Pye, 2005; Zhang, 2008). In a biorefinery, bagasse is typically fractionated into its components and value is added to each component through the production of multiple co-products, such as bioethanol, compounds derived from lignin, specialty sugars, organic acids, fermentation products and energy products including biodiesel, hydrogen and methane (Figure 1).

Pilot plants – facilitating commercial development

Pilot plants are an essential tool for the development of new technologies, bridging the gap between laboratory research and commercial application of the technology. Pilot plants are used to optimise key process parameters such as yield, rate and efficiency at a scale much larger than that used for laboratory development and in equipment that mimic large scale industrial facilities. This allows key process economics to be evaluated and provides information on both the robustness of the process and scale-up data for the design of the commercial facility. Additionally, pilot plants also provide the opportunity to produce a significant amount of product for pre-commercial testing.

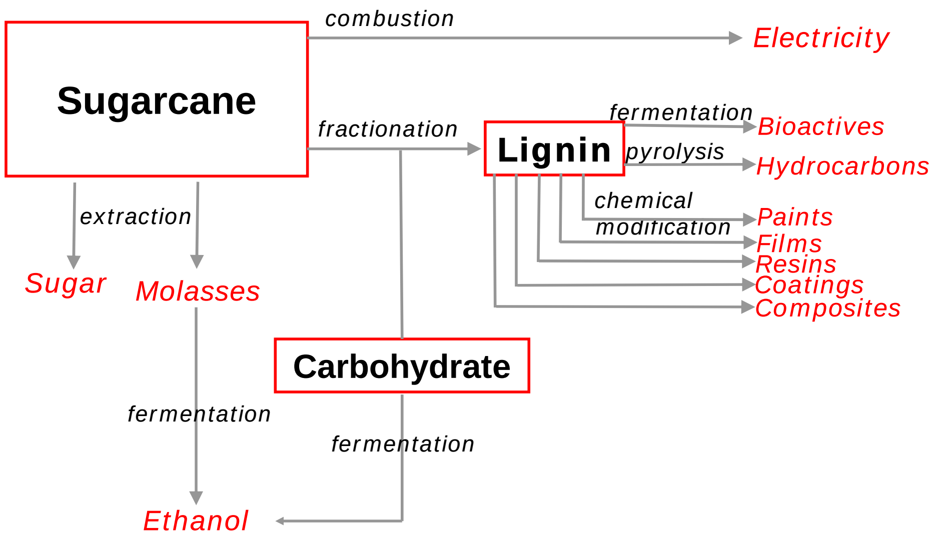

Fig. 1 – A typical concept drawing for a sugar cane biorefinery.

Several pilot scale research facilities exist around the world for the production of ethanol in a biorefinery. Most pilot and demonstration facilities are focussed on a particular process technology, with a only a few facilities capable of demonstrating a broader range of technologies.

MRBPP funding

The Mackay Renewable Biocommodities Pilot Plant (MRBPP) has been funded jointly by the Queensland Government through a $3.1 million loan agreement and by the Australian Government through a $3.4 million grant under the National Collaborative Research Infrastructure Scheme (NCRIS). Further funding of about $1.7 million is to be provided by QUT to ensure that the facility meets its objectives and to underpin the pilot plant as a world class facility.

Queensland Government funding was provided through the then Department of State Development through the Innovation Building Fund. The Innovation Building Fund was established to promote the development of research infrastructure for science and technology in Queensland. The funding under this program was to provide the MRBPP building (factory building, laboratory, offices and hazardous goods containment facilities) and plant and equipment for the pretreatment / fractionation stages and for the separation and concentration of the lignin product.

The NCRIS program was initiated by the Australian Government in 2004-05 to implement "*a strategic and collaborative approach to investment in world-class facilities, networks and infrastructure that are accessible to researchers and meet their long term needs*" (Australian Government Department of Science Innovation and Technology). In the initial round, $542 million was provided to 2010-11, with an initial nine high priority areas identified in the 2006 Strategic Roadmap.

Funding for the MRBPP was awarded to QUT under NCRIS Capability 5.5 Biotechnology Products. The aim of this program was to "develop research infrastructure to assist in the production of pre-commercial quantities of recombinant proteins and biofuels". A total of $23.5 million of Australian Government funding was awarded under this capability at 11 sites around Australia. The overall project value (including other funding sources) totalled $62 million (AusBiotech Ltd, 2008). NCRIS Capability 5.5 is being managed by AusBiotech Ltd.

Under the NCRIS funding rules, it is a requirement that facilities be substantially available for both public and private sector research. The priority and cost of access to any of the NCRIS Capability 5.5 facilities including MRBPP is determined in accordance with an Access and Pricing Code, a copy of which is available on the program website http://www.ncrisbiofuels.org/. Access to the facility for eligible researchers is at a subsidised rate. Organisations considering the use of the MRBPP facility should contact either Ausbiotech or QUT directly.

The NCRIS funding for the MRBPP facility included $2.85 million for hard infrastructure (plant and equipment) and an additional $0.6 million for soft infrastructure (facility labour). Plant and equipment funding under the NCRIS program includes funding for equipment for the saccharification and fermentation facilities and for ethanol product purification and concentration. Funding was also obtained for three product development units (PDU's). A Mettler Toledo RCe1 reaction calorimeter with on-line infra-red detection was purchased to enable the development of comprehensive chemical reaction kinetic information. The purchase of a laboratory scale gas anti-solvent PDU and simulated moving bed chromatography unit will assist with the development of effective strategies for by-product recovery and purification and waste water treatment.

Soft infrastructure funding included salaries for 2 facility employees funded until December 2012. The inclusion of the soft infrastructure is a valuable component of the NCRIS program in ensuring that core skills are developed and maintained in operation of the infrastructure and in ensuring that the access cost is minimised for users of the facility.

Design and construction of the MRBPP

The MRBPP is being constructed at the Mackay Sugar Limited (MSL) Racecourse Sugar Mill to the north-west of the factory boiler station. The facility is being built on land leased from MSL to QUT. Co-location of the facility at the site of a raw sugar factory offers a number of advantages, with the most significant advantage being the development of facility to industrial standards.

Co-location also allowed the facility ready access to large amounts of bagasse and to utilise essential services from the Racecourse Mill site, reducing the cost of construction. Services provided by the site include electrical supply, potable and raw water supply and waste water treatment. The initiative shown by MSL in supporting the establishment of a long term research facility on-site and in providing services and personnel support during the design and construction phase has been invaluable. This support has also ensured that the development of the facility was undertaken according to industrial standards, including rigorous consideration of environmental and health and safety requirements.

A design contract was awarded to Champion Engineers of Mackay in February 2008 to design the 'site infrastructure', including the provision of site services, factory building, laboratory and office facilities, bagasse feeding arrangements, hazardous chemical and waste management facilities for the site. Process design, including the specification of plant and equipment, was undertaken in-house at QUT by process engineers within Sugar Research and Innovation.

Separate tenders were issued for the construction of the site infrastructure and the installation of facility plant and equipment. The tender for the construction of the site infrastructure was issued in October 2008 and the tender awarded to FK Gardner and

Sons in December 2008. At the time of writing, construction was due to be completed by June 2009.

At the time of writing, the tender for the installation of the plant and equipment had yet to be issued. Installation of all plant and equipment is currently expected to be completed by September 2009.

Site services

Electrical supply for the facility is fed from a switch room located within Racecourse Mill which feeds a distribution board located within the MRBPP electrical switch room. Potable water, raw water and fire water are also provided through a common services trench from the Racecourse Mill to the MRBPP site. This trench also returns waste water from the MRBPP site to connect to the mill waste water treatment system.

Steam for the facility is provided by an on-site LPG steam generator. Compressed air and chilled water are also provided from on-site units located within the services room of the MRBPP. A control room inside the MRBPP contains the PLC and operator interface stations.

The facility has designated storage areas for both Class 3 and Class 8 hazardous goods. The site contains a first flush waste water collection system and a dedicated truck unloading area with spill containment. Waste water is able to collected and stored in on-site storage tanks for collection and off-site disposal if required. Solid wastes are also collected for off-site disposal.

Plant and equipment

Plant and equipment for the MRBPP facility has been selected to simulate a range of processes typical of biochemical biorefineries. A typical biorefinery process is shown in Figure 2, in which the major products are ethanol and lignin.

The equipment within the MRBPP has been designed with the flexibility to be able to process not only a range of biomass feedstocks, but additionally utilise a range of pretreatment processes. These include pretreatment using both alkaline and dilute acid chemical processes, at temperatures up to about 220^{o}C and pressures up to 18 bar. Further, the equipment will enable the fibrous material to be “exploded” out of the reactor in a process known as steam explosion.

Providing the flexibility to simulate a range of pretreatment processes maximises the value of the facility both to the Australian research community and to potential industry partners.

Cellulose from the pretreatment stage is able to be hydrolysed using cellulase enzymes to convert the cellulose into glucose and equipment in the MRBPP has been designed to cope with the high solids loading typical of these reactors.

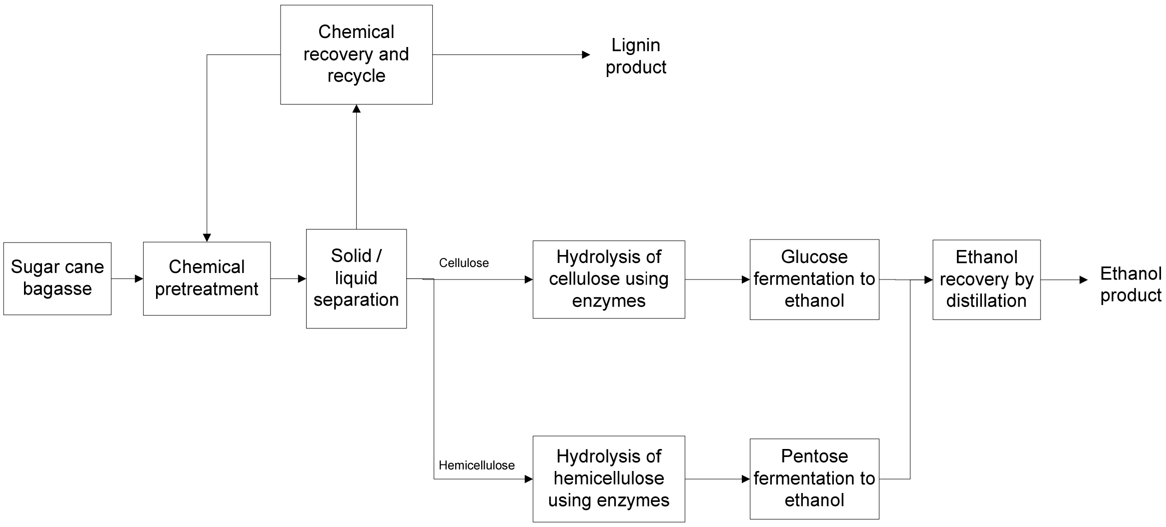

Fig. 2 - Typical biorefinery process diagram.

Glucose and pentose fermentation to ethanol will be undertaken in a range of fermenters of varying scales. The facility has been designed with an enclosed fermentation facility, capable of being certified to physical containment level 2 (PC2). This containment level will enable the facility to trial a wide range of fermentation organisms, including the possibility of organisms that have been genetically modified for pentose fermentation capability.

Ethanol produced in the pilot plant will be concentrated and purified using a distillation column to produce a hydrous ethanol product.

Lignin product recovery

One of the key co-products from the biorefinery will be lignin – an aromatic polymer with many valuable properties. Research work over the last 5 years at QUT and through the Cooperative Research Centre for Sugar Industry Innovation through Biotechnology (CRC-SIIB) has investigated a range of potential uses for lignin including as a phenol substitute in phenol-formaldehyde resins, as a water-borne barrier coating and as a component of lignin-PF films and biocomposite materials (Doherty *et al.*, 2007).

The pilot plant will include equipment for both the delignification of biomass and the subsequent recovery of lignin from chemical solvents. The purified lignin will be able to be produced in significant quantities to enable further product development and testing.

Future developments

The MRBPP is valuable research and development infrastructure for both the Australian research community, future biomass-based industries and in particular the Australian sugar industry. This facility provides unique subsidised infrastructure for biomass utilisation, particularly focussed upon the enzymatic conversion of cellulose into ethanol in an integrated biorefinery.

Additionally, the ability to produce novel co-products such as lignin allow opportunities for large scale product development and testing.

The infrastructure will provide even greater value over time as it evolves to meet the product diversification challenges of the next decade. This evolution will be essential if the facility is to remain a relevant to future research challenges. It is expected that the MRBPP will have sufficient flexibility to undertake pilot trials on fermentation technologies based on sugar, molasses and bioethanol process streams to manufacture organic acids and other products. Chemical derivatisation and transformations may also be possible either in existing equipment or capital expenditure at levels much less than for new green-field developments.

It is envisaged that the MRBPP will in the future need to incorporate additional technologies, including thermochemical processing technologies such as gasification and pyrolysis including downstream catalytic processing. This will assist in ensuring that the MRBPP remains at the forefront of bioenergy research and one of the leading tools for facilitating the introduction of new products into the Australian sugar industry.

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